Quantitative Chemical Mass Transfer in Coastal Sediments During Early Diagenesis: Effects of Biological Transport, Mineralogy, and Fabric

Dawn Lavoie
Code 7431
Naval Research Laboratory
Stennis Space Center MS 39529
phone: (601) 688-4659 fax: (601) 688-5752 email: dawn.lavoie@nrlssc.navy.mil
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LONG-TERM GOAL

The long-term goal of this study is to develop a better mechanistic and quantitative understanding of the effects of biologically-enhanced transport, mineralogy, sediment fabric, and particle surface chemistry on biogeochemical reactions occurring in coastal sediments. Specifically, we plan to provide quantitative expressions of biogeochemical processes from field and laboratory studies and to develop a numerical model of early diagenesis which explicitly accounts for the complex interactions between the structural, mineralogical and biological components of coastal marine sediments

OBJECTIVES

The short term objective for NRL during FY98 was to identify appropriate sediment fabric and benthic macrofaunal parameters, and to define a fabric format that can be incorporated into the existing reactive transport model at Georgia Institute of Technology (GIT). Our hypothesis is that the fabric of bioturbated sediments will affect the permeability of fluids and exchange functions of various solutes.

APPROACH

The approach is a combination of field collection; laboratory analyses of bulk physical properties; macro/microscopic analyses of sediment fabric utilizing x-radiography. CT scanning and transmission electron microscopy; and permeability modeling using effective medium theory. Specifically, NRL (in conjunction with USM) has established a new field site in St. Louis Bay, Mississippi, a fined-grained estuarine site, for studying bioturbation effects on fluid flow using techniques developed during the FY97 Dry Tortugas effort. We have begun characterizing the mineral-organic matter relationship and micromineralogy of the field samples utilizing the new, high-resolution TEM. This work is closely coordinated with Y. Furukawa, funded under Award # NOOO14-98-1-0200, who is analyzing pore fluids, bulk geochemistry and vertical distribution of ^{13}C; and P. VanCappellan who is incorporating our results into the RT model, STEADYSED.

WORK COMPLETED

a. Physical properties analyses from the FY97 Dry Tortugas experiment have been completed. Initial image analysis and EMT modeling of permeability have been completed. These results were presented as part of an invited paper at a geotechnical workshop in Japan in March 1998.
b. Sediments from three tracer experimental sites in St. Louis Bay have been partially characterized. Index properties analyses suggest similar mineralogy, laboratory analyses of permeability have been

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initiated, grain size distribution has not been completed; x-radiography and microscopic analyses indicate differential sediment disturbance by grass growth and burrowing. A significant amount of image analyses still to be done should help understand the pore water irrigation results (Furukawa). We have just begun identifying specific OM morphology and types; NRL's new high resolution TEM has just come on line.

RESULTS

a. EMT modeling of permeability from North Key Harbor in the Dry Tortugas, Florida, on a representative section of carbonate matrix (k = 1.6 x 10^{-4} cm/s) agreed well with bulk laboratory analyses of permeability coefficient (1.5 x 10^{-4} cm/s) and in situ permeability coefficient of 7.1 x 10^{-4} cm/s. To model permeability, the microfabric was quantitatively characterized. The protocols developed are being used to model more complicated fabric of fine-grained coastal sediments. Serial SEM sections have been stacked to create a virtual 3D sediment section. Techniques to model 3D permeability are being developed. Image results from the Dry Tortugas experiment suggest that burrows (open or filled) result in differential fluid flow on the microscale (Figure 1).

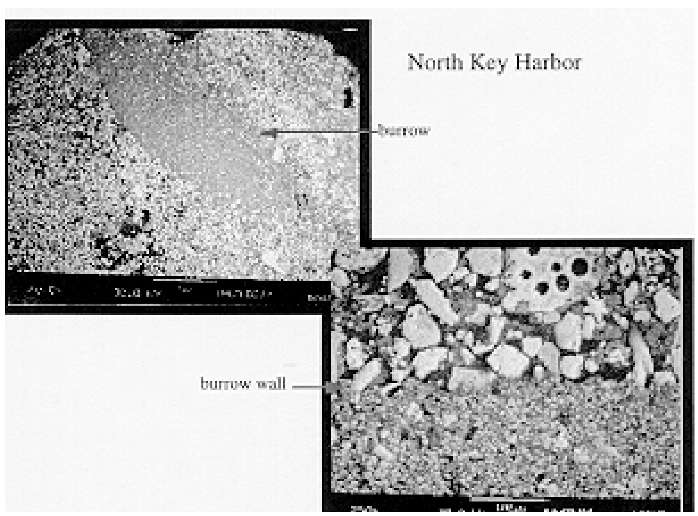

Figure 1. Carbonate sediments recovered from North Key Harbor, site of the first 13 C tracer experiment, indicate a number of burrows, both active and filled. Differential grain size results in differential pore distribution and permeability on the microscale.

b. Sediments recovered from the St. Louis Bay experimental sites are heavily burrowed, and in two cases, disturbed by the growth of marsh grasses. The sediments are fine-grained clays (mineralogy not completed) of approximately 69 % porosity and permeability coefficient of 6.1 x10^{-4} cm/s. The image analysis to date has concentrated on the effects of grass (mm-scale, x-radiography) on fluid flow. The grasses, modeled as a partially-filled tubular pore network give a bulk sediment permeability of 6.8 x 10^{-4} cm/s. In situ permeability measurements using NRL's falling-head field permeameter are planned as ground truth.

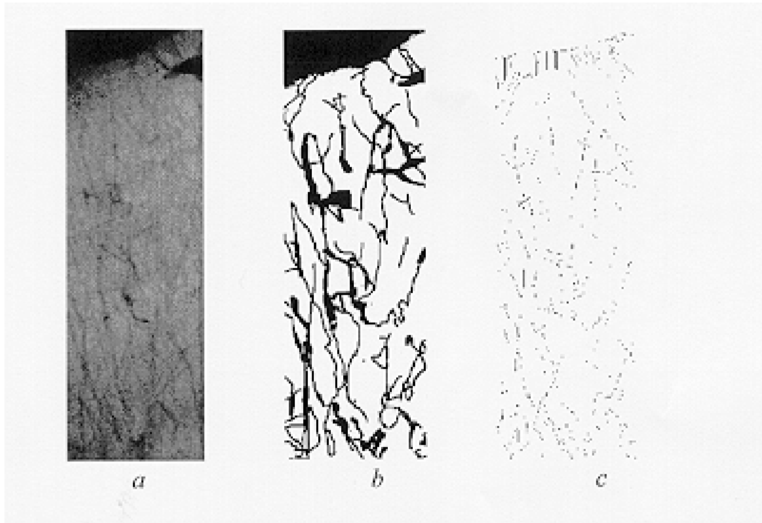

Figure 2. a. x-ray image of sediment illustrating the pervasiveness of grasses throughout the section. b. The grasses are imaged as tubular networks in a binary image. c. Erosion-dilation, Euclidian Distance M apping and other standard image analysis techniques are used to identify and quantify the required microfabric parameters (e.g., pore body and throat radii, connectivity, autocorrelation function, chord size distribution) used as input for modeling permeability.

IMPACT/APPLICATION

A better understanding and mathematical description of biologically-enhanced transport, sediment fabric and particle surface chemistry during shallow diagenesis will allow us to better model and predict the fate and transport of particles and associated pollutants, By concentrating on fine-grained sediments over the next few years, we hope to make a significant contribution understanding harbor pollution solutions. In addition, by understanding the effect of fabric changes during diagenesis, we will be able to better predict sediment physical and geoacoustic properties of interest to the MCM community, (predicting mine burial in shallow coastal regions) and the acoustic community for modeling acoustic propagation.

TRANSITIONS

Techniques for quantitative characterization (2D and 3D) of sediment macro and microfabric will be transitioned to other ONR-funded programs including the High-frequency Sound Interaction in Ocean Sediments: Modeling Environmental Controls DRI. It is anticipated that results from this effort will contribute to applied environmental programs in the future.

RELATED PROJECTS

This project has leveraged the NRL 6.1 core program (Microenvironmental Studies) for support, particularly for the field effort, and will continue to do so. Microfabric results have been used in modeling efforts to predict permeability and will undoubtedly continue to benefit other programs with similar requirements, e.g., the ONR High Frequency Sound Interaction DRI will require quantitative pore space and particle geometry data for prediction of permeability and porosity.

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